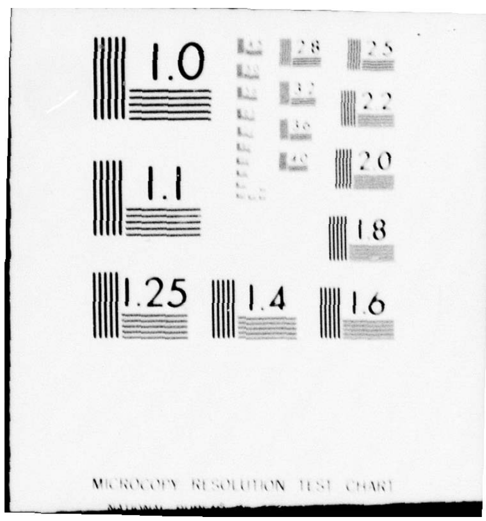
AD-A061 609 DEFENCE RESEARCH ESTABLISHMENT OTTAWA (ONTARIO) F/G 17/2
POWER SUPPLIES FOR ARCTIC RADIO REPEATER SYSTEMS,(U)
SEP 78 G D NAGY
UNCLASSIFIED DREO-R-787 NL

1 OF 1
AD
A061 609

END
DATE
FILMED
2-79
DDC


1.0
1.1
1.25
1.4
1.6
1.8
2.0
2.2
2.5
2.8
3.2
3.6
4.0
MICROCOPY RESOLUTION TEST CHART

3

RESEARCH AND DEVELOPMENT BRANCH
DEPARTMENT OF NATIONAL DEFENCE
CANADA

LEVEL II

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

DREO REPORT NO. 787
DREO R 787

POWER SUPPLIES FOR ARCTIC RADIO REPEATER SYSTEMS

by

G.D. Nagy

PROJECT NO.
54-03-07

SEPTEMBER 1978
OTTAWA

RESEARCH AND DEVELOPMENT BRANCH

DEPARTMENT OF NATIONAL DEFENCE
CANADA

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

REPORT NO. 787

14 DREO-R-787

6 POWER SUPPLIES FOR ARCTIC RADIO REPEATER SYSTEMS.

by

10 Gerard D. Nagy
Energy Conversion Division

PROJECT NO.
54-03-07

11 SEP[redacted]78
OTTAWA

*Presently employed with CRAD/DTA(L), National Defence Headquarters.

12 50 p.

78 11 20 021

404 576

ABSTRACT

This feasibility study assesses various long-lived, self-contained 30-watt power supplies for an Arctic Radio Repeater System. The study involves a review of the state-of-the-art, availability and cost of five candidate systems; batteries, fuel cells, radioisotopic thermoelectric generators, fueled thermoelectric generators and windmill-battery systems. The above five candidates were also assessed as standby power units. Reliability, service and maintenance requirements are considered since the application calls for one year unattended operation and servicing by light helicopter on a single annual flight for all sites.

Only zinc/air batteries with lead/acid batteries for the standby system are available now. Their cost is moderate, but zinc/air cells are heavy and must be replaced each year. Other systems could be available in the 1980's but they would require various amounts of development work and evaluation in an arctic environment. Recommendations and priorities for development of the systems which could replace the zinc/air cells at a later date are given.

RÉSUMÉ

La présente étude évalue la possibilité d'alimenter un relais hertzien dans l'Arctique à l'aide de blocs autonomes de 30 watts et de grande vie utile. L'auteur donne un aperçu des plus récents perfectionnements dans le domaine et livre une analyse de la disponibilité et du coût de cinq dispositifs: les accumulateurs, les piles à combustible, les générateurs thermoélectriques à radio-isotopes, les générateurs thermoélectriques à combustible et enfin les accumulateurs à éolienne. Il examine également l'utilité de ces dispositifs en tant que dispositifs de secours. Il a également tenu compte des exigences en matière de fiabilité et de entretien les dispositifs ne doivent nécessiter qu'un entretien annuel, effectué au moyen d'un hélicoptère léger.

A l'heure actuelle, les seuls blocs de secours possibles sont les accumulateurs au zinc et à l'air de même que les accumulateurs au plomb.

Ceux-ci sont d'un coût raisonnable, les accumulateurs au zinc et à l'air présentant toutefois l'inconvénient d'ètre lourds et de ne durer qu'un an. Il semble que les autres genres de blocs d'alimentation seront sur le marché dans les années 1980, mais il reste à les perfectionner et à en faire l'essai en milieu arctique. L'auteur indique donc les priorités du développement des blocs d'alimentation qui pourraient remplacer un jour les batteries au zinc et à l'air.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

INTRODUCTION

Draft PDP G1413 defines an operational requirement to develop a new two-way, medium-data-rate communications system for CFS Alert to Ottawa (1). This system would include terrestrial radio repeater stations from Alert to Eureka with a satellite link from Eureka to Ottawa. The terrestrial link is necessary because much of the terrain between Alert and Eureka is over the horizon with respect to suitable satellites in stationary orbit.

It is anticipated that the radio repeater system will include 10 to 15 isolated i.f. repeater stations located in remote areas. The power requirement of these stations will be about 30 watts and the stations must operate reliably between -55°C and +30°C in winds up to 120 mph with reliability over a one year period of unattended operation. The equipment for each station should be helicopter transportable and serviceable by light helicopter on a single annual flight for all sites. An additional requirement imposed on the power supplies is the need for standby power. The reserve power units should function automatically, be able to operate 30 days and have a standby capability of 5 years. The PDP would provide $100K for development of a power supply during the FY 77/78. The target date for installation of the system is the summer of 1978 or the summer of 1979. However, delays in obtaining approval of the PDP and constructing the stations make 1979 or 1980 more probable dates.

In March of 1976, Honeywell Incorporated was awarded a contract to build and test, by July 1977, a demonstration radio repeater system for use in an arctic environment (2). The system includes two unattended radio repeater relay terminals, complete with receivers, transmitters and power supplies, which were installed 24 to 25 miles from Alert, the base station. In this demonstration system signals are transmitted from the base station to the first repeater, back to the base station, then on to the second repeater and back to the base station, providing four relay legs over mountain terrain, water and ice. The transmitted power for these terminals is 100 mW, about one-tenth of the power required for the actual repeater stations. The mini-systems were installed and tested during August and September of 1976 and have worked well after a few installation and start-up problems (3). Difficulties were encountered in anchoring one of the antenna structures; one could be anchored into rock while the other required surface weights to provide stability. Power is supplied by Cipel air depolarized primary cells. Up to 24 alarm parameters can be monitored. These include; high and low temperatures, high and low battery voltages, high wind speeds, high and low power transmission and incoming signal strengths. More details will be given about the system in the next section; General Consideration for Power Supplies.

The Honeywell demonstration system does not address the problem of optimum choice of power supplies and it was necessary that DCEM, the directorate tasked to carry out an indepth study of the system, gain knowledge of the capabilities, limitations and cost effectiveness of possible power supplies for use in the Arctic Repeater stations. As a result, in March of 1976, DREO was tasked by DCEM to conduct a feasibility study of reliable, long-lived, self-contained 30-watt power supplies for operation in the Arctic. This study was to be done concurrently with the Honeywell feasibility tests (4). The study which is reported here involves an assessment of the following candidate power supplies: batteries, fuel cells, fueled thermoelectric generators, radioisotope thermoelectric generators, and windmill-battery systems. Among the factors considered are present limitations of the systems and recommendations for future research and development work.

GENERAL CONSIDERATIONS FOR POWER SUPPLIES

TEMPERATURE AND CLIMATE

Climatic conditions influence various types of power supplies differently. For batteries and fuel cells the operating conversion efficiency and voltage decrease with decreasing temperature. In some cases snow can be put to good advantage to act as an insulator for the power system. The temperature under 6 feet of snow when the ambient temperature is -25 to -30°C is only -8°C (5). However, preliminary investigation of the proposed repeater sites showed that snow coverage is not significant to provide insulation. The best sites for the relay stations are on the crests of hills where there is the least amount of snow. The efficiency and voltage of thermoelectric devices increase with decrease in temperature. However if moving parts are involved they must be kept from icing up and open-flame type burners must be protected from the wind. For windmill-battery systems, low temperature can have an effect on the bearings and mechanical linkages. Icing and fine granular snow, common on Ellesmere Island, can be a problem especially if the structure is downwind from geological features such as receding glaciers and open water.

At the present time, the exact sites have not been chosen and the only data that exists on the actual conditions of wind and temperature are for Alert and Eureka. While it is possible that the inland sites may be colder in winter, the data for Alert and Eureka can be considered as a close guide.

Figures 1 and 2 show in graphical form the average monthly variation of temperature for Eureka and Alert respectively over a one-year cycle. This is taken from DOT data for the period of 1931 to 1960 (6).

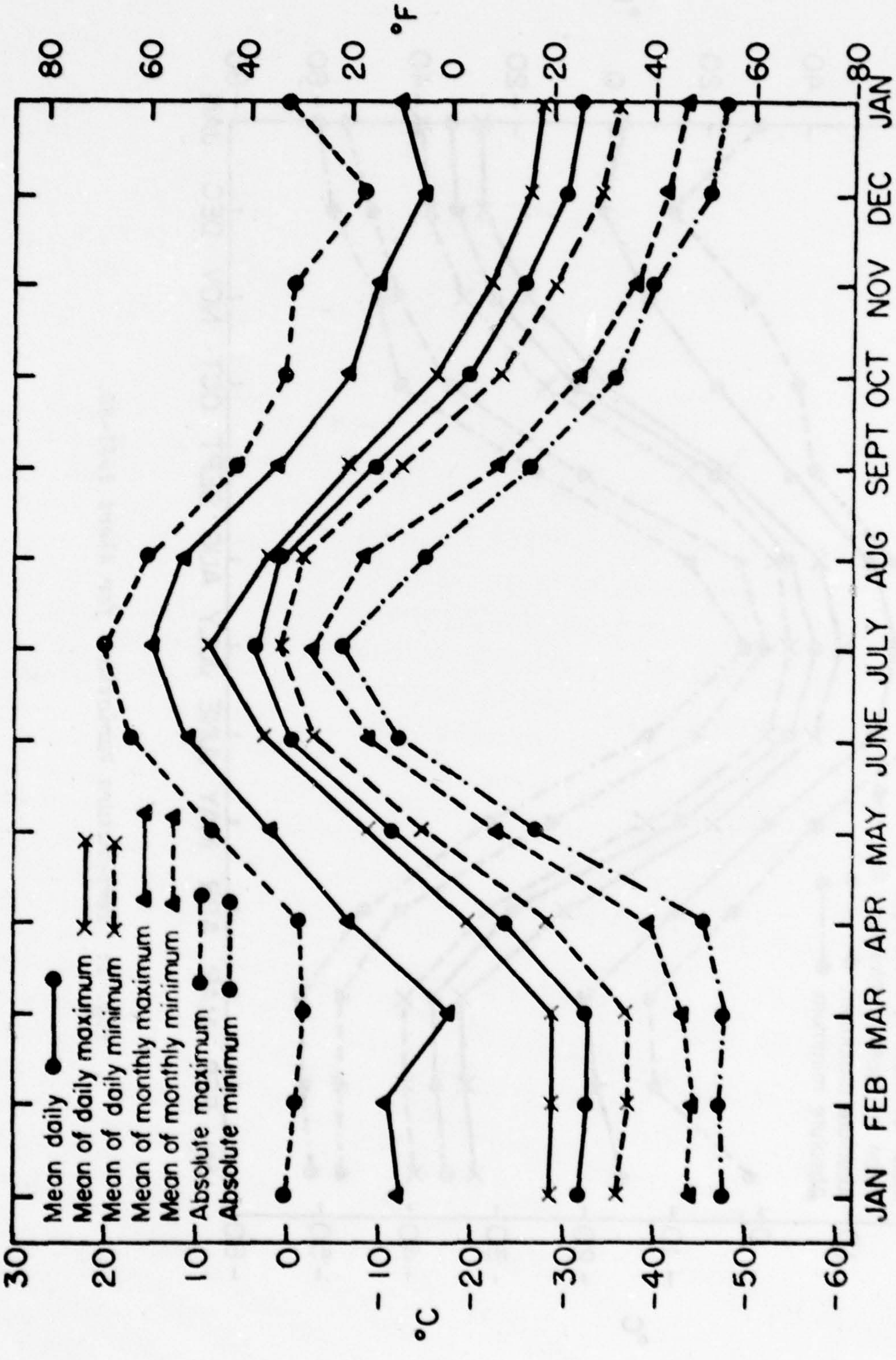


Fig. 1: Temperature Variations for Eureka 1931-80.

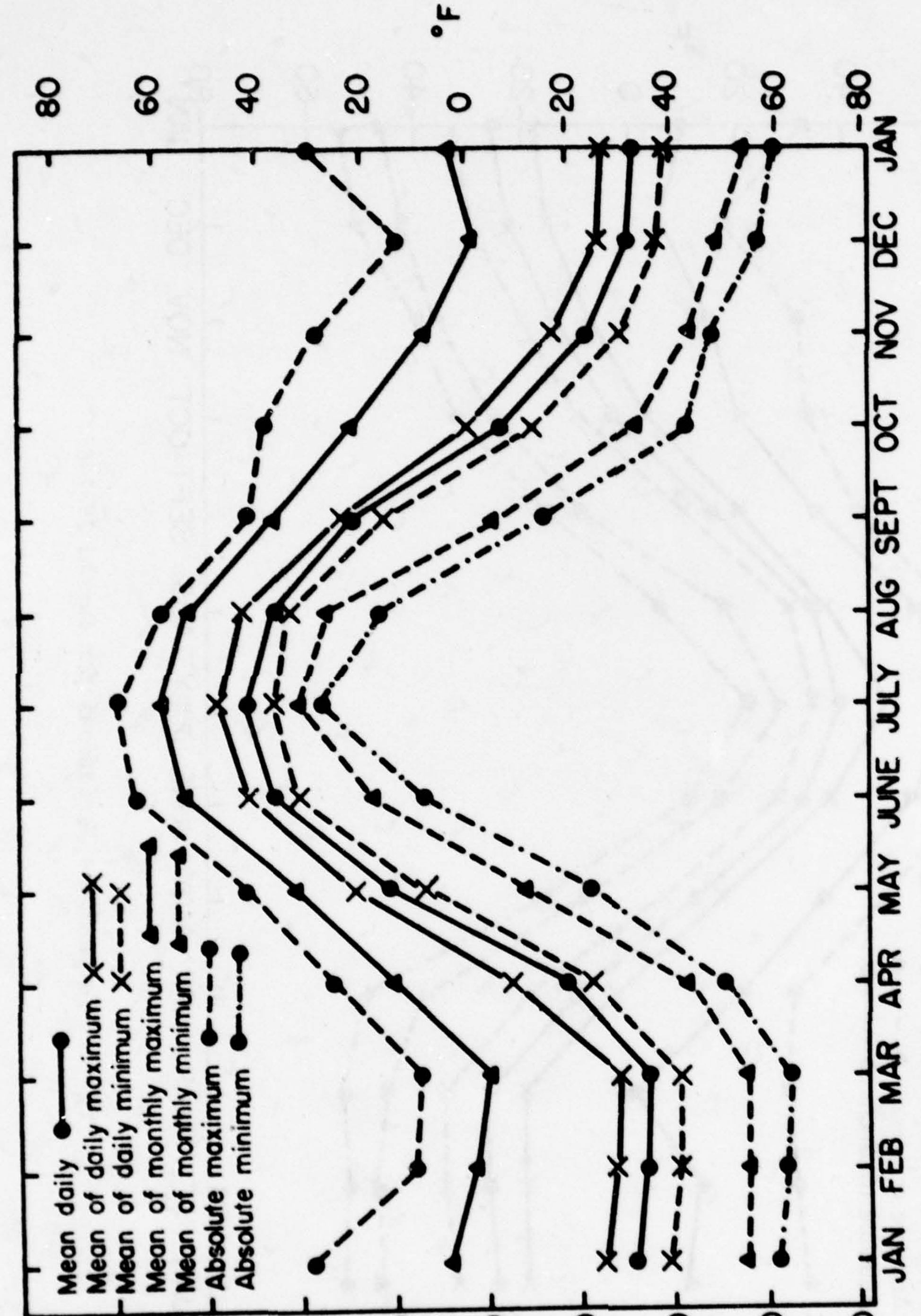


Fig. 2: Temperature Variations for Alert 1931-60.

The following data have been plotted for each month: mean daily temperature, mean daily maximum, mean daily minimum, absolute monthly maximum, absolute monthly minimum, mean of monthly maximum and mean of monthly minimum. As can be seen the mean daily temperature during the winter months is between -33°C and -38°C. This in itself does not present a severe problem for the most promising power supplies. The desired output can normally be maintained, the power supply can be kept insulated or can supply enough heat to keep itself warm as for example; thermoelectric generators and fuel cells. However, the mean monthly maximum and minimum curves indicate that the temperature fluctuates significantly from the mean daily temperature. Insulation would keep the battery warmer during a decrease in temperature but would also have the adverse effect of keeping the power supply cooler than the ambient when the temperature rises again. Also some systems cannot be effectively insulated, for example, wind-mills, air-breathing batteries and fuel cells.

It is therefore necessary to consider the extreme temperature, i.e. the absolute minimum when choosing a system. Based on the available data, -55°C is not unrealistic. The probability of sustained periods of time at this temperature even at inland sites would be very low, but because of the nature of the application, communications during very low temperature periods is vital. A detailed temperature profile for the actual sites is essential to see just how valid the above assumption is.

When choosing a system that is affected by the temperature and/or other climatic conditions, one must consider three factors. 1) Does the temperature or climatic conditions have an effect that would render the system inactive permanently or for an extended period of time? It must be remembered that during the winter months servicing is virtually impossible and the conditions such as low temperature, blowing snow or high winds which may render the system inactive are the same ones which could prevent a crew from travelling to service the breakdown. 2) Does the temperature have an effect on the output power capability of the system? This will vary from system to system, in fact some systems may be affected in the ways discussed in both 1) and 2). It may be necessary to overdesign and protect the system in the first instance and then modify it as necessary on future refurbishings. 3) The third consideration is weight and size. The larger and heavier the unit, the more trips will be necessary for installation and replenishing. This can be a very important consideration in extended periods of bad weather. Also the bigger and heavier the units are, the better the weather conditions would have to be for reasons of safety for the transporting crew.

POWER REGULATION

The regulation for the power supplies will have an input-output characteristic like that shown in Figure 3. The curve is that for the system with the 100 mW prototype transmitter, but is envisioned to be essentially the same for the actual model which is designed to operate at 1 watt of transmitted power. The prototype uses 4.4 watts while the 1 watt unit is expected to draw about 30 watts from the power supply.

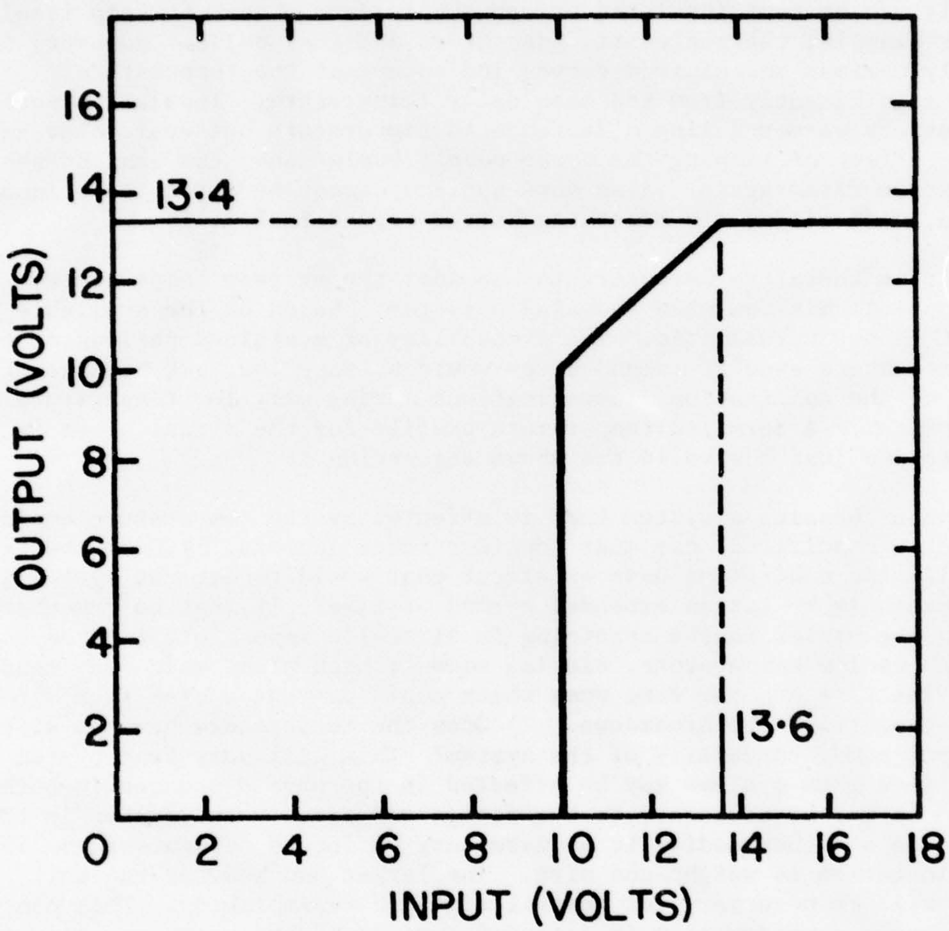


Fig. 3: Hurricane Voltage Regulator July 76.

The regulator will accept voltages between 10.0 and 18.0V. Above 18.0V and below 10.0V the system is shut off. Between 13.6 and 18.0V the output is 13.4V regardless of the input voltage. The input power to the regulator in this range of voltage is essentially constant and the current from the power supply will increase as its voltage drops. Between 10.0 and 13.6V the output of the regulator follows the supply voltage with a slight loss of approximately 0.2V in the regulator circuit. The load on the power source below 13.6V can be considered constant and hence, the power requirement falls as the voltage and current drop.

The air-depolarized cells used for the prototype stations worked well (3). These were Cipel AD608Z, 2000 Ah cells. Twenty-four cell batteries were used for each station, 2 parallel strings of 12 cells each. Initially the voltage of the batteries, at around -3 to 0°C, was 15.7V with a total current drain of 280 mA, for a power consumption of 4.4 watts. In the winter of 1976/77, after use for 4 months the voltages and currents remained in the ranges of 15.0 to 15.8V and 280 to 290 mA, respectively (7). No correlation between temperature and voltage or power consumption could be detected. However, the batteries were less than 25% discharged and the results are not surprising. The results do show that these batteries appear capable of supplying the required power. Preliminary studies by Honeywell, during which they discharged a freshly activated cell at 150 mA for 30 days at -62°C to -55°C showed no problems with the electrolyte freezing (8). The battery maintained a 1.3V output during the period.

TRANSPORTATION

Transportation costs were not taken into account at this time. Rough figures are available but they depend upon the mode of travel and will undoubtedly increase. It is expected that the most costly part of the trip would be from Alert or Eureka to the actual sites. Total costs would then depend on the distances to the sites and upon the total helicopter time required to complete the deliveries and not necessarily on the actual weights of the delivered equipment. However, transportation costs from $0.20 to $2.50* a pound to Alert have been quoted and weight and sizes of the units are given so comparisons can be made. It will be seen that for most systems considered, yearly replenishment of fuel will be affected by transportation costs. The windmill-battery system and radioisotope thermoelectric generator will incur transportation costs only for the initial installation as fuel replenishment is not required on a yearly basis.

---

* This cost and all subsequent cost figures are based on 1976.

BATTERIES

The main parameters which must be considered with regard to battery design are voltage, accessible capacity and the rate of discharge. These are interrelated and depend also upon the operating temperature. Generally, both the voltage and capacity that one obtains from a battery will decrease as either the temperature decreases or the rate of discharge increases. Also for any temperature, the voltage of the battery will decrease as it becomes discharged. These effects are more severe for primary than for secondary batteries. For the Arctic Repeater stations, installation of batteries in late summer has the advantage that relatively fresh batteries would be used during the winter and the more rapid decrease in voltage towards the end of discharge is partially compensated for by an increase in voltage and available capacity resulting from the higher temperatures of late spring and summer.

Fortunately, the current drains for the Arctic Repeater station are very low (the one year rate). As a result, the decrease of capacity and voltage at extremely low temperatures are not as severe as one would encounter if the cells were discharged at the more usual rate, that is in 1 hour to 100 hours. To obtain low temperature data, the magnitude of the decrease in capacity had to be extrapolated from high current drain data obtained at higher temperatures, with the freezing point of the electrolyte defining the lower limit of operation. The assumption, supported by empirical data, was made that above the freezing point of the electrolyte, the current limiting factor is chemical in nature. This leads to the conclusion that the minimum temperature one can operate the battery and obtain a certain constant fraction of the nominal room temperature (20-25°C) capacity, will be a function of the logarithm of the current drain. Therefore, from plots of the percentage of the nominal room temperature capacity versus temperature for high current drains, one can make graphical extrapolations to obtain a similar curve for the current drain required for the system. Using this data, the battery can be designed to meet the low temperature capacity for operating an Arctic Repeater station. In most cases, a further 5% allowance was made to allow for differences in individual cells.

With regard to the decrease in voltage with temperature and state of discharge, some of this effect is compensated for in the allowance made for the decrease in capacity with temperature as the data used is for the same cut-off voltage regardless of temperature. However, further allowances must be made to ensure there is always sufficient voltage above 10.0V to operate the regulator. For this purpose a typical temperature coefficient for voltage of 2.5 mV/C° was used. Therefore, to ensure 10.0V at -55°C room temperature cut-off of 12.0V was chosen as one of the design parameters in determining the number of cells one must connect in series for the battery.

The above considerations provide redundancy in the system as it is difficult to completely separate all of the parameters, and in some cases it is known that an effect may have been included in more than one calculation. However, for the sake of reliability and since overdesign in the first instance can be easily rectified on future refurbishings, this approach was chosen to provide a power supply at the earliest date without a separate evaluation study in the Arctic.

The batteries considered are relatively maintenance free. Except where stated later for specific systems, batteries need only be kept above the freezing point of the electrolyte. Secondary batteries will need proper charge regulation and checking and possible addition of electrolyte at one-year intervals.

PRIMARY BATTERIES

The primary batteries that were considered are listed in Table I. More details on each of the systems are given in the following sections. A wide variety of systems and conditions are included for comparison purposes and to indicate the effect of temperature on the number of cells required. One of the conditions considered besides 20°C and -55°C is operation at -8°C which corresponds to batteries buried in snow when the ambient temperature is -25°C to -30°C.

No data exists of cases of a discharge into the type of regulator described earlier. Most of the data is for constant current drain or constant load drain. For the purpose of this application, it was assumed that the number of parallel strings required, would be that needed to provide an average current of 2.2A at 13.6V (i.e. 30 watts). Knowing the ampere-hour capacity per cell and assuming that this capacity will be completely utilized during the year of discharge, the average current for one year's operation per cell and hence the number of strings needed can then be calculated. This method can be expected to yield a larger quantity of cells than actually needed. Above 13.6V, constant power is withdrawn and hence the current will be below 2.2A. Below 13.6V, since the load is essentially constant and the power drops as the voltage decreases, the current will decrease also and be below 2.2A. At 13.6V, the current will be a maximum of the order of 2.2A. For an accurate calculation, one requires the integrated charge needed and until this figure is obtained during an actual discharge with a regulator under arctic conditions, this method is the closest safe approximation one can make. A sufficient degree of redundancy, as discussed earlier, is provided. For comparison purposes, to choose the most suitable battery system one does not need the exact parameters. All the systems would be adjusted in the same proportion.

TABLE I

30 Watt Primary Batteries for One Year Operation

Battery Type	Conditions	Cells (Series by Parallel Arrangement)	Weight lb	Volume cu.ft.	Cost $(a)
#6 Dry Cells	-17°C to -23°C (b)	5484 (12 x 487)	12,418	146	20,000
	Buried in snow at -8°C to 20°C	4596 (12 x 383)	9,767	122	16,755
Manganese Alkaline D-size	-55°C	35,832 (12 x 2956)	10,080	90	35,800
	Buried in snow, -8°C	27,768 (12 x 2314)	7,810	70	27,800
	20°C	25,704 (12 x 2142)	7,230	65	25,700
IMATRA Manganese Alkaline	-55°C	1,614 (3 x 538)	12,428	137	29,050
	Buried in snow at -8°C to 20°C	1.146 (3 x 383)	*8,825*	*98*	*20,630*
Li/SO_2 D-Size	-55°C	13,030 (5 x 2606)	2,390	33	65,150(c)
	20°C	12,090 (5 x 2418)	2,210	20	60,450(c)
Cipel AD600 10,000 Ah Air Cells	-55°C	120 (12 x 10)	(d) 11,160 (17,160)	240	24,000
	Buried in snow at -8°C to 20°C	24 (12 x 2)	(d) 2,323 (3,432)	42	4,800
Cipel AD608Z 2000 Ah Air Cells	-55° to 20°C	120 (12 x 10)	(d) 3,000 (4,200)	56	3,960

a. Based on 1976 prices for cells only.
b. Freezing point of electrolyte.
c. Based on a projected quantity cost of $5.00 per cell.
d. Present small quantity cost $10.00 per cell.
d. Non activated weight, amount in brackets is activated weight.

#6 DRY CELLS

These cells are the largest convenient size in which the ordinary dry cell is produced and are especially designed for low current applications. A #6 dry cell can deliver 54 Ah. The average current required would therefore be 6.23 mA per cell. The weight and volume occupied by the cells are 2.12 lb and 0.0265 cu. ft. respectively and present cost is $3.65 per cell. The nominal voltage of these cells is 1.5V, but the voltage does fall off gradually with discharge. A typical cut-off voltage is 1.0V per cell. They are not useful for the Arctic Radio Repeater because the electrolyte freezes at about -17°C or lower and are only included here for comparison purposes. The decreases in capacity for operation at -20°C and -8°C would be 20% and 3% respectively of the room temperature values at the current drains expected.

MANGANESE ALKALINE

These cells are basically similar to conventional dry cells. The main differences are the use of an alkaline electrolyte and in some cases improved electrodes which give better low temperature behaviour. They also provide more capacity than the conventional dry cell. At the present time the main types in production that are of interest are the D-size and a Finnish battery with the trade name of IMATRA. The latter uses flat plate construction and multicell packaging but does not behave as well as the D-size cell at low temperatures and high rates because of the type of intercell connector used. The low temperature behaviour could possibly be improved with a re-design of the intercell connectors. Both types are capable of operating down to -55°C at the current drains required.

The D-size cells have a nominal capacity of 9 Ah and would be discharged at an average current of 1.03 mA. Each cell weighs 4.5 oz and occupies 0.0025 cu. ft. Present cost is $1.00 per cell. At -8°C the decrease in capacity would be 3% while at -55°C, one should obtain 75% of the room temperature capacity.

The IMATRA batteries come in a 6-volt size with a nominal capacity of 55 Ah. The average current drain would be 6.35 mA. Each module weighs 7.7 lb and costs $18.00. At -8°C and -55°C the capacities one can obtain are respectively 95% and 66% of that at room temperature.

LITHIUM BATTERIES

These batteries are relatively new and offer extremely good low temperature performance and high energy densities. Two types are being produced on a limited scale at the present time, those (eg. Li/SO_2) with organic electrolytes and those (eg. Li/thionyl chloride) with inorganic electrolytes. The manufacturers have experienced difficulties with these cells from the safety point of view. There have been instances of explosions and fires which have been caused by faulty cells and/or usage. At the present time these cells do not have full approval for air transportation and require more development work to make them safer. However, the low temperatures of Ellesmere Island would be beneficial from the safety point of view.

The most convenient size of the Li/SO_2 cells presently available is the D-size. Larger sizes have been built but the demand is low and they are costlier because of the more limited production. This system has a voltage of approximately twice that of the manganese alkaline cells. They have a nominal capacity of 8 Ah which would be discharged at an average current of 0.91 mA per cell in the Arctic Radio Repeater system. Each cell weighs 2.93 oz. At -55°C one can expect in excess of 90% of the room temperature capacity at the required current. Besides the hazards, another disadvantage of these cells is the cost. At present they are approximately $10.00 per cell, but it is expected that the price will be reduced to $5.00 each when large scale production is achieved. This latter figure was used in Table I and even so it can be seen that compared to other systems these are prohibitively expensive.

Larger versions of the Li/thionyl chloride cells are being developed by GTE and Honeywell. These cells give indications that they will have low temperature behaviour similar to the Li/SO_2 cells. Cells in 30 and 200 Ah sizes have been built for laboratory use. The 200 Ah cells are expected to give 153 to 175 Wh/lb and 12-15 Wh/cu. in. One of the goals is to produce a 500 Ah cell with energy densities of 20 Wh/cu. in. and 300 Wh/lb at a cost of about $35 per kWh. Therefore at 20°C, one would require 190 (5 x 38) of the 500 Ah cells at a weight of 875 lb and a volume of 7.6 cu. ft. The cost would be about $9200. For the 200 Ah cells, the weight would be about 1700 lb; the volume, 12 cu. ft. and 570 cells would be required. However, it must be remembered that these cells are in the early stages of development and the above calculations are based on design goals not yet attained. A conservative estimate of availability would be the mid 1980's.

CIPEL ZINC/AIR CELLS

These cells have been produced for a number of years and are very simple in construction. They are designed to operate at low current drains and low temperatures. A typical cell, AD608Z, which will give 2000 Ah is shown in Figure 4. There is also a larger version, the AD600, which will deliver 10,000 Ah. In both types of cells, a large porous activated carbon cathode, which converts the oxygen in air to hydroxyl ions, is at the center. The anode is a large annular ring of zinc which surrounds the carbon electrode. The electrolyte is concentrated potassium hydroxide (20% KOH by weight). Solid KOH is placed in trays inside the battery and the cell is activated by adding water to dissolve the KOH.

The open circuit voltage is 1.45V. When put on discharge, at the one-year rate, the voltage falls fairly rapidly to about 1.25V until the cell is about 10% discharged. Between 10% and 80-90% discharge the voltage remains fairly constant, after which it falls rapidly again to the cutoff voltage, normally 1.0V.

These cells behave in the same manner as the other primary batteries considered with regard to the decrease in voltage with temperature. But they are different from the primary batteries in that they will deliver the rated capacity so long as the drain is below a critical current which is a function of the temperature. Because of the similar design and construction of the two sizes of batteries, the values of the critical current are about the same for the two cells. The reported critical currents based on batteries completely discharged to an end point of 1.0V per cell are as follows: above -10°C, the critical currents are 1.8 and 2.0A for the 10,000 Ah and 2,000 Ah cells respectively; at -40°C the corresponding values are 0.2 and 0.25A. The data does not go below -40°C. Extrapolated values of the data supplied by the manufacturer give 0.065 and 0.09A respectively at -55°C.

However, the data supplied by Honeywell on the 2000 Ah cells discharged at 0.15A at -55 to -62°C indicate that the critical currents are higher for batteries that are not completely discharged. From Figure 1 and 2, it can be seen that if the batteries are installed in August, they would, at most, be 50% discharged during the period that the minimum temperatures are experienced. When 75% of the year has passed after installation, the temperature would have risen above -40°C. DREO undertook a study to determine the currents that can be drawn from the AD608Z cells with various KOH concentrations and states of discharge at temperatures down to -55°C. At -55°C, a depth of discharge of 50% and the optimum KOH concentration, the critical current at a 1.0V cutoff was 0.2A. At -55°C and 75% depth of discharge the cell would not support any current drain and at -51°C, at a current drain of 0.2A, the voltage was 0.86V. At 75% depth of discharge and at -40°C, the critical current was 0.5A. For both 50% and 75% depths of discharge the cell voltages were very sensitive to the current drain for temperatures between -50 and -55°C. Tests are being done to determine if a high KOH concentration

Fig. 4: Cipel AD608Z Zinc/Air Cell.

has any long term effect at the temperatures at which one expects these batteries will have to operate. No significant performance deterioration is expected.

Above -8°C, one can use the nominal capacity of the cells and the actual current drains to determine the series/parallel arrangement of the cells. Below -8°C one must base the total number of cells required on the critical current drain and corresponding cell voltage. In Table I, based on the DREO results, a limiting current of 0.2A per cell at -55°C and 50% depth of discharge was used for both sizes of cells to determine the number of cells required. No allowance was made for differences in capacity of individual cells as the nominal values quoted are about 90% of that which can actually be obtained.

At the 10.0V cut-off of the regulator, an average of 0.85V per cell and a current of the order of 1.62A would be required. Twelve cells in series would be adequate to meet the voltage requirement. Because of the extreme sensitivity of the cell voltage to the current drain, eleven cells in series would result in a voltage at -55°C that would be too close to the 10.0V cut-off of the regulator, especially if the low temperature occurred when the depth of discharge was greater than 50%. For the AD600 cells at -8°C and above, two strings in parallel would be required. One string would only last 4500 hours. At -55°C, 10 parallel strings would be required to produce a minimum current of 1.62A. For the AD608Z cells one would need 10 parallel strings regardless of the temperature. This arrangement would meet the minimum current requirement at -55°C and for all temperatures gives more than 9100 hours even if the current drain was at the maximum, i.e. 2.2A, for the entire discharge. As mentioned earlier, the actual current will be lower, between 1.62A and 2.2A and thus, the actual run time could be considerably greater than 9100 hours. Because of the large capacity of the cells it would be advisable to have each string of the battery fitted with a diode to prevent damage to the other strings, if one cell or string should happen to become faulty or short circuited. Twelve cells in series would provide sufficient allowance in voltage for the diode.

The AD608Z cells each weigh 25 lb unactivated and 35 lb activated. The volume occupied by each cell is 0.46 cu. ft. They cost $33 per cell. The corresponding figures for the AD600 cells are; 93 lb, 143 lb, 1.7 cu. ft. and $200 per cell.

SECONDARY BATTERIES

Secondary batteries are not considered to be suitable for use as the main power supply for this application. In general, they will be costlier and heavier than primary batteries because of low energy densities. Typical energy densities are of the order of 7 to 12 Wh/lb. The heaviest of the primary batteries in Table I, eg. the #6 dry cells and manganese alkaline, have energy densities of 25 to 45 Wh/lb. On the other hand, the Li/SO_2 system can give 90 to 100 Wh/lb and the Cipel Zinc/Air gives 60 to 80 Wh/lb. In addition charging equipment would have to be transported to the sites to

recharge the batteries on a yearly basis. For comparison purposes only, two systems, nickel/cadmium and lead/acid were considered and are listed in Table II*. The calculations are based on batteries having 13 to 14 volts and giving 9000 hours of operation at the maximum current the battery would deliver. Since the current drains and temperature coefficients of voltage are low, of the order of 0.1 to 0.5 mV/C° (9), the voltage and capacity required at a temperature of -55°C will not be significantly different from that at room temperature.

The nickel/cadmium cell has a nominal open-circuit voltage of 1.3V and 10 cells would be needed in each series string. Pocket plate batteries rather than the sintered type were chosen even though the pocket plate type have a lower discharge voltage especially at lower temperatures. However, this disadvantage is more than offset by the lower cost. The 415-Ah cells weigh 42 lb, occupy 0.36 cu. ft. and cost $211.50. The weight and volume of the 488-Ah cells, which cost $250.50 per cell, are comparable.

The lead/acid cells are cheaper but heavier than the nickel/cadmium cells. Two sizes were considered. They are both of the stationary type and designed for low current drains. Both sizes operate at a nominal 2.0 volts per cell. One version can deliver 480 Ah/cell and the other 2200 Ah/cell. The expected life of these cells are 15 and 30 years respectively at normal temperatures. Each 480-Ah cell weighs 100 lb, occupies 0.86 cu. ft. and costs $69.36 at the present time. The 2200-Ah cells weigh 667 lbs each, occupy 3.85 cu. ft. and cost $474.65.

The lead/acid batteries would require modification to the electrolyte to allow them to operate down to -55°C. Normally the electrolyte has a specific gravity of less than 1.25 at 25°C**. Electrolyte of specific gravity 1.25 will freeze at -55°C. Also the electrolyte concentration decreases and the freezing point increases as the battery is discharged. The specific gravity increases with decreasing temperature. Therefore the specific gravity of the electrolyte must be chosen so that at the end of discharge or during the period of minimum temperature, it is above 1.25.

Cells with 1.28 and 1.30 sp. gr. electrolyte can be discharged 15 and 26 Ah per litre of electrolyte respectively before the electrolyte reaches 1.25 sp. gr. Therefore, for the 480-Ah cells which contain 22.5 litres of acid, and the 2200-Ah cells, if one were to use 1.30 sp. gr. electrolyte, one could completely discharge them and the freezing point of the electrolyte would remain below -55°C. With 1.28 sp. gr. acid, (freezing point -65°C) one could discharge them 340 Ah and 1560 Ah respectively before the specific gravity reached 1.25. The 1.28 sp. gr. electrolyte could be used, since from Figures 1 and 2, after 8 months of use (assuming August

---

* In Table II, specific battery sizes and manufacturers are listed. This is not to be construed as a recommendation as to the most desirable size or brand. There are many manufacturers who produce batteries of comparable size, quality and cost. For the purpose of this report all of the different types were not compared. The batteries chosen are considered to be typical of the many produced.

** All figures quoted for specific gravity of the sulfuric acid electrolyte in this and subsequent sections refer to the specific gravity at 25°C/25°C and not the actual specific gravity at the freezing point quoted.

TABLE II

Secondary Battery Systems for One Year Operation at 30 Watts and -55°C to 25°C

System & Type	Cells Required (series x parallel) Arrangement	Weight (lb)	Volume (cu. ft.)	Cost $**
NiFe-Jugner Ni/Cd KAP 42 415 Ah*	490 (10 x 49)	20,580	177	103,620
NiFe-Jugner Ni/Cd L411 488 Ah*	410 (10 x 41)	17,265	148	102,710
VARTA Lead/Acid 480 Ah*	294 (7 x 42)	29,400	254	20,400
VARTA Lead/Acid 2200 Ah*	63 (7 x 9)	42,020	243	29,900

* Or equivalent.

** Based on 1976 prices.

installation) the period of minimum temperature would have been passed and the temperature should be above -40°C. Less than 320 and 1470 Ah would have been drained from the 480 and 2200-Ah cells respectively during the 8 month period.

One of the reasons that long life is obtained from the lead/acid cells is the slow rate of self-discharge with the low concentration of the electrolyte that is used (1.22-1.25 sp. gr.). The higher the concentration, the higher is the self-discharge and deterioration. However, at the low ambient temperatures in the north, the self-discharge and corrosion processes will be significantly decreased and this should compensate for any adverse effects of the use of a higher concentration of electrolyte.

CONCLUSIONS FOR BATTERY POWER SUPPLY SYSTEMS

It is obvious from Tables I and II that the most inexpensive battery power source for the application being considered is the Cipel AD608Z. In its unactivated state and for operation at -55°C, the AD608Z system is at least a factor of three lighter and a factor of about two smaller than the other systems with the exception of the Li/SO_2 system. The cost would be less than one-fifth of the other systems. This is true even when one compares the operation of the AD608Z cells to the AD600 cells. The low limiting current of the 10,000 Ah cells dictates the use of a battery with over four times the required capacity. The zinc/air cells must be chosen over the presently available Li/SO_2 cells on the basis of cost. If the lithium/thionyl chloride cells mentioned earlier are developed to the extent anticipated they may be a possible replacement for the AD608Z cells.

It would be cost effective to ship the batteries in the unactivated state to Ellesmere Island. The cells then could be filled with water at a base station and transferred to the site. The trip from the base station to the site would be beneficial in helping to thoroughly mix the electrolyte.

It is realized that none of these batteries permit servicing of all of the sites by one yearly light helicopter flight, however, the battery is the only known power supply that could definitely be ready for use in 1979.

FUEL CELLS

Fuel cells are electrochemical devices in which the energy of a fuel and of an oxidant are transformed into direct current electrical

energy*. However, unlike batteries, the chemicals are stored outside the cell. The reactants are fed into the cell and are usually in the form of gases. The main advantage of fuel cells is the high energy density achievable when a relatively large quantity of energy must be generated.

At present there are no readily available systems in the 30-watt range. Fuel cells have been used in space, but were very costly and while reliability was important, they were not designed for, or capable of, extended continuous operation. Industry is still doing development work so units are available on a specially made basis. In essence, use of fuel cells to this date has been only for very special or experimental applications. Acceptance by the users still has to be achieved.

Basically, the reactants used for almost all fuel cells are hydrogen and oxygen. The fuel and oxidant need not necessarily be in the form of the pure gases. The hydrogen can be obtained from any hydrogenous material that can be made to give up its hydrogen. Conventional fuels such as natural gas, gasoline, diesel fuel and methanol can be reformed to produce hydrogen and carbon dioxide. Generally, suitable treatment of the gases formed, to remove impurities and unwanted gases is necessary. This requirement can add complexity to the system and reduce the overall efficiency. Hydrides can be decomposed to generate hydrogen gas. Hydrazine has been used directly by addition to the electrolyte. Oxygen can be obtained from air or by the decomposition of an oxide or oxygen containing compounds such as a chlorate.

Since the reactions occurring at the electrodes are chemical in nature (i.e. oxidation of hydrogen and the reduction of oxygen to produce water and electrical energy) the rate of reaction andhence the limiting current one can draw from the cell is, as it is for batteries, greatly dependent upon the temperature. However, the conversion processes involved in practical fuel cells are not 100% efficient, and the losses can provide heat to maintain a proper operating temperature. This internal heat generation is especially useful for cells which are operated at elevated temperatures.

Fuel cells can be classified into three types based on the three kinds of electrolyte used (9). The electrolyte can be: molten salt, alkaline or acid.

MOLTEN SALT FUEL CELLS

Molten salt fuel cells normally use molten carbonates at about 500°C, in a porous ceramic matrix, as the electrolyte. The salts can be a mixture of lithium, sodium and potassium carbonates. This system can operate on reformed fuel which contains carbon dioxide. The carbon dioxide does not

---

* This section will not deal with all of the advantages and disadvantages of fuel cells or the many types. For further information the reader is referred to reference 10.

have to be removed as it is a necessary reactant in the process at the cathode (electrode) where it combines with oxygen to produce carbonate ions, the charge carrying species in the electrolyte. These systems are in a very early stage of development and are intended to be used in large-power applications. It is expected that they will play an important role for applications requiring tens of kilowatts of power. None are available at the present time and the development work necessary to produce a suitable power supply for the Arctic Radio Relay system would be very expensive. In a northern environment it may be difficult to maintain good efficiency for a 30W unit in view of the high temperatures required to keep the electrolyte molten. The development cost is difficult to estimate, but it would be greater than for the other systems and molten salt fuel cells would not be available before the mid or late 1980's. Molten salt fuel cells cannot be considered to be a feasible system for the application of interest here.

ALKALINE FUEL CELLS

These fuel cells have aqueous potassium hydroxide as their electrolyte. They offer the highest efficiency in converting hydrogen and oxygen to electrical energy (and water) so would require the smallest amount of consumables of any fuel cell system.

However, alkaline fuel cells are not recommended for this application for several reasons. Water is produced in the electrolyte by the reaction of hydrogen and oxygen and a careful balance of heat and gas circulation is required to remove it. The complexity of the necessary controls, aggravated by the need to operate the fuel cell in this very small system with a wide range of ambient temperatures, is predicted to seriously degrade the overall efficiency and the system reliability. Another concern is cell life; previously cell voltage degraded below practical limits before 2000 hours of operation but recent tests on cells using a potassium titanate matrix have demonstrated 10,000 hours of operation without serious voltage decay.

Problems can be caused by oxides of carbon if present in the reactants. Carbon monoxide can poison platinum electrocatalysts, especially when electrodes are operated at moderate temperatures (i.e. below 200°C). Carbon dioxide present in air and in impure hydrogen such as the fuel produced by reforming a hydrocarbon must also be avoided; the carbon dioxide reacts with potassium hydroxide to yield carbonates which degrade fuel cell performance. For the Arctic Radio Repeater application, pure hydrogen and oxygen could be supplied and then electrolyte contamination would not be a problem.

Considerable work has been done on a direct oxidation methanol fuel cell which uses an alkaline electrolyte (11). However, development of this system is not receiving significant attention at the present time.

ACID ELECTROLYTE FUEL CELLS

Acid electrolytes are more suitable than alkaline for air breathing fuel cells because carbon dioxide does not affect the acid. There are two types of acid cells that warrant consideration, phosphoric acid and solid polymer electrolyte (SPE) fuel cells.

PHOSPHORIC ACID FUEL CELLS

The use of phosphoric acid fuel cells is technically possible today. They have been run on pure hydrogen and on hydrogen/carbon dioxide mixtures obtained by reforming hydrocarbons. In large sizes, these fuel cells are in a high state of development, but they cannot be readily scaled down to smaller sizes and be developed for installation in 1979. No phosphoric acid fuel cell system has been actually run trouble free for the 8600 hours that constitutes one year's continuous operation. Both United Technologies and Engelhard have demonstrated operating times between 1000 and 5000 hours. During the past few years, Engelhard was developing a small (30-100 watt) fuel cell which used evaporation techniques to remove water. This unit was considered to be capable of operating on air, with the water produced exhausted to the atmosphere or collected. However, it has recently been learned that Engelhard is putting less emphasis on this cell in favour of an SPE type of cell for fuel cells up to 30 watts.

As with alkaline cells, water removal from phosphoric acid fuel cells is a problem. For low temperature, remote application, the electrolyte dilution and leakage are considered to be too difficult to overcome and so phosphoric acid cells should not be considered seriously for this application at the present time.

SPE FUEL CELL

The most advanced type of fuel cell suitable for low temperature, low power applications uses an acid electrolyte which is a solid polymer. This type is being developed by G.E. and Engelhard, the latter placing emphasis on low temperature operation. At the present time G.E.'s fuel cell appears to be more advanced and G.E. controls pertinent patents. In these fuel cells, hydrogen is converted at one electrode (the anode) to hydrogen ions which then migrate through the electrolyte to the oxygen electrode (the cathode). There the hydrogen ions combine with hydroxyl ions, formed by the reduction

of oxygen, to produce water. If the cell is properly engineered the excess water drips down the outside of the electrode to a tray. No complex pumps or evaporator systems are required. There is very little degradation of the electrolyte. Some water does enter the electrolyte but it is necessary to keep the solid electrolyte moist. At present G.E. projects that 40,000 to 50,000 hours of operation can be obtained. One four-cell stack has been run for 40,000 hours, but no complete multicell systems have been produced and fully evaluated.

A SPE fuel cell system consuming hydrogen and oxygen, which must operate over a large ambient temperature range extending from −55°C to +35°C must be insulated to keep the cell from freezing. It is estimated that a 30 watt system would generate 20 watts of heat by operating at 0.74 volts per cell or 60% efficiency; this heat could maintain a well insulated system 60 or 70 Centigrade degrees above a −55°C ambient or at 5 to 15°C. At the high end of the ambient temperature range, the cells would be warmer and are expected to operate at 0.9 volts per cell corresponding to 75% efficiency. Then the 10 watts of waste heat are estimated to maintain the same insulated package 50 Centigrade degrees above the 35°C ambient or at 75 to 80°C.

There would be both advantages and disadvantages associated with the use of pure oxygen rather than air in an arctic fuel cell installation. A much larger volume of cold dry gas would pass through the cell stack if air were used as the source of oxygen and this would adversely affect the water balance of the electrolyte as well as increasing the amount of heat required to prevent freezing of the electrolyte water produced by the fuel cell reaction. The air system could not be sealed and there would be the possibility that the air inlets and outlets might frost over. The use of pure oxygen would increase the cell voltage and system efficiency and, therefore, slightly reduce the amount of hydrogen consumed. On the other hand, large weight, volume and financial penalties would have to be paid for the transport and storage of pure oxygen.

30-WATT FUEL CELL SYSTEM FOR USE IN THE ARCTIC

If development work were to proceed on a 30-watt fuel cell for arctic use, it should be directed towards the SPE type of cell. The fuel cell would ideally be contained in a 45-gallon insulated drum with some dead space to hold the water produced. The insulation on the drum would have to be engineered to allow the heat generated in the fuel cells to maintain the cell temperature at the optimum value and above the freezing point of water. The water on or in the fuel cell itself must be kept from freezing. The weight of the fuel cell would be about 50 lb. The insulated drum would bring the total weight to between 100 and 150 lb.

Work would have to be done on the effect and prevention of freezing damage on the system and container, on devising the most efficient method of water removal from the cell and subsequent storage or explusion from the system at low temperatures, and on designing the optimum type and quantity of insulation required for the container. To do this work would require

3 men for one to one and one half years and $100K. The production-type cells would cost $25K each for the first two and approximately $1.2K for each fuel cell after that. They would have an estimated life of at least 3 years before replacement would be necessary.

The best cost estimate for alkaline fuel cells or phosphoric acid systems with complex water removal systems would be between $500K and $1M. The complete fuel cell system would require from three to five years more time for development than the SPE fuel cell systems.

There are four methods that one could consider for fuel storage; in high pressure gas tanks, in conventional cylinders, as solid fuel or cryogenic storage. In arriving at the cost estimates (conservative at best) that follow, it was assumed that an air-breathing fuel cell would be used. It is the most desirable type because it eliminates the need to transport one of the fuel cell reactants. If oxygen from the air cannot be used and oxygen has to be provided, the cost, weight and volume of the reactant storage system would be about 50% greater than for provision of hydrogen alone.

A high pressure hydrogen tank with sufficient fuel for one year's operation would be a 38-in. sphere weighing 930 lb including 30 lb of hydrogen. The shipping volume would be 32 cu. ft. The cost of a set of two tanks per site would be $64K after the initial development and tooling costs of $75K. The cost of the fuel would be of the order of $240 per site per year. Two tanks would be required per set, one at the site and one in reserve to be used for filling and transporting the fuel from the hydrogen source to the site. It is estimated that these tanks could be available in 1979 and that they would last 10 years.

The high pressure tank storage system is preferred to the use of conventional cylinders because the latter are two heavy. Twenty T-size cylinders, each weighing 190 lb would be required for each site. The total weight of the cylinders would be 3800 lb as opposed to 900 for the high pressure container. Over a 10-year period, the rental cost of a set of tanks for each site, based on $320* per tank, would be $6.4K for the hydrogen container. Transportation costs in excess of $1.80 per lb and spread over 10 years would make the high pressure tanks less costly in the long run.

The hydride system for one year's operation would weigh about 300 lb and occupy 10 cu. ft. (12). The development cost for this fuel container and method of releasing the hydrogen gas is estimated to be roughly equivalent to the development cost for the high pressure tanks. The estimated cost of the fuel, based upon use of calcium hydride, would be about $6.5K per site per year. Based upon a 10-year life for the high pressure tanks, over a 10-year period the two systems would have almost identical costs (neglecting the investment aspect of present and future expenditures). The main advantage of the hydride system is the lower weight and the possibility of

---

* This figure is based on an 18-month rental period for each year of use. An additional 6 months would be required to transport the cylinders to and from the site. The cost of purchasing the cylinders would be comparable as 2 sets would be required per site.

adopting other, possibly less expensive reactants.

It is more difficult to determine costs for cryogenic storage systems. The technology is relatively new and amenable to sudden improvements. Estimates between $10K and $100K per tank have been made depending upon whether the tanks would be tailor-made, whether the manufacturer has experience, or whether use could be made of existing sizes. Experience with fabrication of cryogenic tanks for use in hydrogen-powered automobiles could reduce the mass production cost, in the future, as low as $200 per tank for tanks of the capacity to supply hydrogen for one year to a 30-watt fuel cell (13). However, for the purposes of this report $50K to $65K per site has been adopted. The cost and weight would be roughly the same as that for the high pressure tanks and the volume comparable to that for the hydride systems. A more thorough investigation would have to be carried out to obtain more refined estimates.

Presently, the transportation regulations for hydrogen are stringent and varied and depend upon the mode of storage. The regulations, especially for air or sea transportation would have to be investigated and possibly altered to make practical the provision of hydrogen to northern sites.

An assessment of a fuel cell system would involve the evaluation of two units in Ottawa followed by evaluation at Ellesmere Island. DREO could conduct the evaluation in Ottawa since DREO is in the process of procuring two 30-watt SPE fuel cells through the U.S. Army. The SPE fuel cells with suitable fuel storage could be ready for evaluation at Ottawa by the beginning of 1979. A 1-year evaluation could start in the Arctic in 1981. If the evaluation results warrant it, general installation could occur in the summer of 1983. The tests at Ellesmere Island in the period of 1981-82 would be done using the fuel cell as the primary power supply on two stations, with the main power supply which had been used up to that time as the back up.

The total development costs for a fuel cell and storage system would be $200K over the next 4 years. The initial cost to produce the power supplies for 10 stations with 2 fuel cells* and 2 sets of tanks per site for high pressure or cryogenic storage would be $664K or $66.4K per site ($640K for tanks and $24K for fuel cells). Based on a 3-year life for the fuel cells and a 10-year life for the tanks, the cost per station per year over a 10-year period** would be $9.3K ($200K for development, $640 for the tanks, $65K for the fuel cells and $24K for hydrogen). Again the investment value of money has been neglected. The corresponding cost per site per year for the hydride system would be $9.2K ($200K for development, $65K for fuel cells and $650K for the fuel).

Fuel cells should not be eliminated because of cost. The low weight makes them a potentially acceptable power source. The technology of light weight tanks is advancing. If fuel cells are to be considered as the prime

---

* This assumes there are 20 fuel cells in all. One spare for each site is recommended for the first production. After that 4 spares total should be adequate.

** A 10-year period was chosen here and in subsequent economic considerations as the lowest common period over which costs could be amortized for comparison purposes.

power source, it is recommended that studies be initiated on the insulated container, the fuel storage system and on fuel cell development based upon the first tests on the container and fuel. At this time the solid polymer electrolyte (SPE) fuel cell is the leading contender for this application. If the fuel cell is accepted, it is predicted that major system maintenance costs would be for transportation and replacement.

FUELED THERMOELECTRIC GENERATORS

Thermoelectric generators convert heat into electrical energy making use of the Seebeck effect whereby two junctions of dissimilar metals at different temperatures set up a potential difference between the two junctions that can cause an electrical current to flow in an external load.

There are basically three types of heat sources for heating the hot junctions. Radioisotopic sources will be dealt with in more detail in the next section. Flame types burn the fuel with an open flame. The third type uses a hot catalyst bed to oxidize the fuel into carbon dioxide, water and heat.

The presently available units, based upon combustion, can be run on readily available hydrocarbon fuels and can be very rugged. Low ambient temperatures tend to increase the performance since ambient air is used to cool the cold junction and the potential difference increases as the difference in temperature between the hot and cold junctions increase. Generally there are no moving parts so thermoelectric generators are simple and there is little danger of mechanical parts freezing up in cold weather.

On the minus side, the efficiencies of generation of electrical power are low, of the order of 3 to 7% based upon the heat content of the fuel used. Also to obtain optimum output the hot junctions of the generator are sometimes operated near the upper temperature limit of the junction material and local hot spots and failure can occur. However, technology in the area of burner and module design is well advanced and reliability of the elements is very good. In some models, fans and fuel regulation features are incorporated to improve cooling and combustion. These features are beneficial for attended operation, but can severely limit reliability during unattended operation, especially at low temperatures. Large amounts of water vapour are produced by the combustion and must be exhausted without freezing up the gas exit ports.

The main disadvantage of the open flame type for unattended operation is the possibility of flame-out due to the wind or temporary blockages in the fuel line. Tests have been conducted with a 12-watt 3M generator at DREO (14). There were instances of flame-out in high winds and the unit had to be restarted manually. Work has been done on better wind proofed

burners, but the requirement to withstand 120 mph winds is considered to be beyond the present state of the technology. For units in the kilowatt range the burner assembly and heat exchanger can retain sufficient heat for a few seconds to restart the flame, but for a 30-watt unit the heat content would not be sufficient. The Department of Indian and Northern Affairs has used this type of unit in the Kootenay, Wood Buffalo and Watabu National parks system since 1967 (15). They have experienced flame-outs and trouble with keeping the propane flowing in the gaseous state in cold weather. The boiling point of propane is about -42°C. Pressurizing the propane container with nitrogen causing the liquid propane to flow, and/or heating the tanks and gas lines have eliminated most of these problems. The B.C. Government (16) has recently converted many of the flame-type generators on microwave repeater stations to primary batteries because of the flame-out problems. None of the systems mentioned above were designed for the long unattended periods of operation required by the Arctic Radio Repeater system.

The catalyst type thermoelectric generator is not susceptible to flame-out as no open flame is involved. The combustion region is sufficiently insulated and the temperature of operation is sufficiently high to re-ignite the fuel, and restart the unit automatically on resumption of fuel flow after the flow has been shut off for minutes (up to 20 minutes at 25°C). High wind can have a small effect by exerting a back pressure on the propane or by diluting the propane-air mixture to a lower level. However the design is such as to cut down the wind effect at the burner inlets.

The catalyst type of thermoelectric generator is the only one considered to be feasible for one year unattended operation in the Arctic. Figure 5 shows an installation of a 40-watt unit being tested at DREO. It is a Telan 2 model produced by the Teledyne Corporation and operates on propane. The main disadvantage in its use in the north is that propane would have to be shipped to the site and maintained above -37°C, since the propane vapour pressure at the pressure regulator for the burner must remain above 10 psig. This is not considered to be too serious. Only about 5% of the heat produced by propane combustion is converted to electricity. The remaining heat is available to keep the fuel warm. Also since the conversion efficiency is greater at low temperatures, surplus power can be used to electrically heat the tank and fuel feed lines. At -40°C the unit will deliver 150 to 165% of the power produced at 25°C.

The Department of Indian and Northern Affairs has been using a number of 25-watt units of this type since 1971 without encountering serious problems (15). Nitrogen was added to the propane, however this may not be feasible in the Arctic as it could severely increase the weight and volume of gases that have to be transported. Insulation and auxiliary heating of the fuel when needed is preferred but this would require about $25K of development work and in addition would cost about $200 per installation.

Maintenance is reported to be minimal. The only requirement is to replenish the fuel and replace the catalytic burner which is expected to last in excess of five years.

The choice between a 30- or 40-watt unit cannot be made until after the DREO evaluations are complete. There should be enough waste heat and

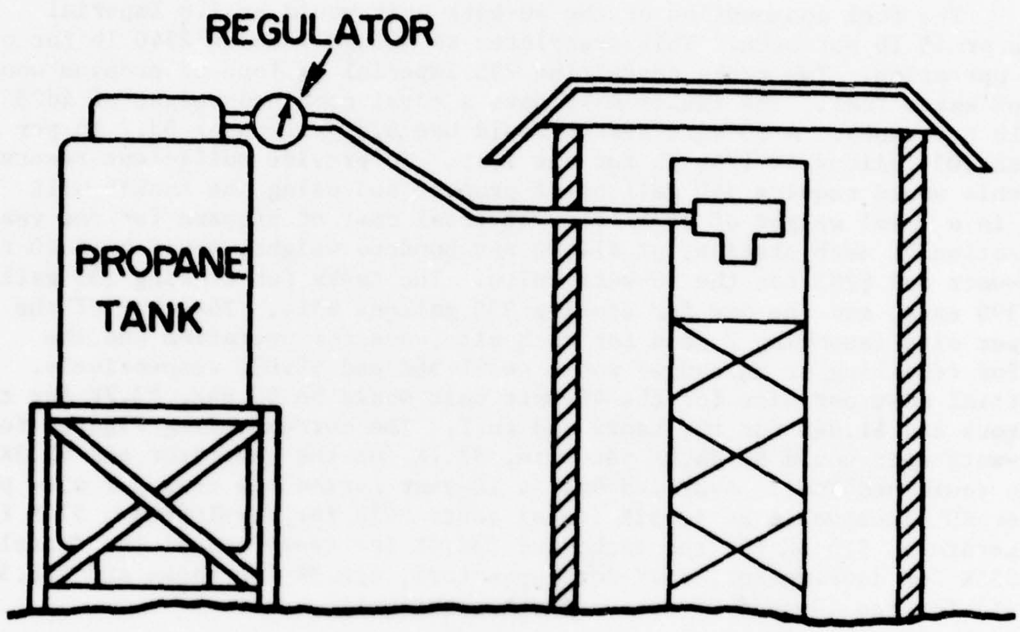


Fig. 5: TELAN-2 40 Watt Thermoelectric Generator at DREO.

extra power available from the 30-watt generator to keep the fuel and fuel lines warm. However, this presupposes that an efficient heat exchanger can be designed. The performance of the two different sized units may be much the same because the 40-watt unit would require more heat since it needs larger fuel tanks and quantity of fuel.

The weights would be 73 lb and 93 lb and the basic prices $2.5K and $3.5K for the 30-watt and 40-watt units respectively. Both occupy the same volume, 5.4 cu. ft.

The fuel consumption of the 40-watt unit would be 7.8 Imperial gallons or 45 lb per week. This translates to 405 gallons or 2340 lb for one year's operation. Two tanks containing 235 Imperial gallons of propane would give 16% extra fuel. The tanks* will have a total combined weight of 4825 lb (2413 lb per tank). A 30-watt system would use 5.8 gallons or 33.7 lb per week and 302 gallons or 1750 lb for one year. To provide sufficient reserve fuel, this would require 350 gallons of propane and using one tank** will result in a total weight of 3570 lb. The total cost of propane for one year of operation of each station, at $14.00 per hundred weight, would be $380 for the 40-watt and $285 for the 30-watt units. The tanks for storing 235 gallons cost $390 each, and the one for storing 350 gallons $515. The cost of the tanks per site (assuming 2 sets for each site, one for operation and the other for refilling or exchange) would be $1.56K and $1.03K respectively. The initial cost per site for the 40-watt unit would be $5.64K, $3.7K for the generators and $1.94K for the tanks and fuel. The corresponding figures for the 30-watt unit would be $4.0K per site, $2.7K for the generator and $1.3K for the tanks and fuel. Averaged over a 10-year period the cost per site per year for 10 sites would be $1.53K (total cost: $25K for development, $74K for the generators, $15.6K for the tanks and $38.0K for fuel) and $1.18K (total cost: $25K for development, $54K for generators, $10.3K for tanks and $28.5K for fuel) for the 40- and 30-watt units respectively.

The volume occupied by a 334 U.S. gallon tank is 115 cu. ft. This is for the rectangular or shipping volume even though the tanks are cylindrical. Therefore for the 40-watt unit the two tanks would occupy 230 cu. ft. For the 30-watt unit the fuel supply would occupy 190 cu. ft.

Besides evaluation for the Arctic Radio Repeater system, the purpose of obtaining a unit for DREO was to study: methods of designing a suitable heat exchanger for the tanks and fuel feed lines, restart capabilities, conditions necessary for minimum fuel consumption and operating temperature. A secondary aim, though not specifically for the repeater application, is to consider ways of utilizing the waste heat to provide heat for sheds or the electronic package if it were required at a later date.

It is felt that the earliest that a thermoelectric system can be available for installation and operation is 1980. The plan was to evaluate the unit at DREO and design a suitable heat exchanger during the winters of

---

* Tanks are filled to 85% capacity so tanks with 334 U.S. gallon capacity can be used.

** A tank with 500 U.S. gallon capacity is suitable.

1977/78 and 1978/79. This should be followed by the operation of two units for one year at Alert during the winter of 1979/80. The evaluation at Alert is essential. Operating data does exist for other similar sites which are, on the average, about 10 Centigrade degrees warmer than Ellesmere Island, but at which the mean daily temperature in winter is a few degrees above the critical temperature of -37°C for the fuel. On Ellesmere Island on the other hand, the mean daily temperature is a few degrees below -37°C.

The above dates assume that all the tests are favorable and that units and heat exchangers could be procured by early 1980. If changes are required after the preliminary testing, the earliest and probably most realistic date for installation would be early 1981, to allow for any redesign and testing.

RADIOISOTOPIC THERMOELECTRIC GENERATORS

Thorough evaluation of this type of generator will have to await completion of a contract with AECL for a feasibility study to look at the availability of radioisotopic thermoelectric generators, any development areas that would have to be studied and possible solutions to the technical problems suggested (17). The estimates quoted in the following parts of this section are based upon the best available data in 1977. Significant changes, either as increase or decrease, could occur in the cost and life figures. Any delays in availability dates would push the date further into the future.

At the present time, no work is being done on 30-watt units in Canada or the U.S. AECL no longer makes the Maple series of low power radioisotopic thermoelectric generators. Interest in the U.S. is on larger (2 kW) isotopic thermomechanical devices using Brayton or Stirling engines. However, the U.S. are beginning to define a requirement in the 30-50 watt range (18). Generators produced in the U.S. normally use Strontium 90 as the heat source. There appears to be a shortage of Strontium 90, thus manufacturers of small units will not quote on price and availability. AECL uses Cobalt 60 because it is readily available and in use in their cancer therapy units. Strontium 90 would be preferable for the Arctic Repeater system since it has a 25-year half-life compared to 5 for Cobalt 60.

AECL foresees the necessity of a program to redesign the Maple series to minimize radiation damage to the thermoelectric elements and scale-up the electrical power output. A possibility is to put the elements outside the radiation shielding to decrease damage. If contracted to develop and produce units, AECL will work on the thermal source and sub-contract work on the thermoelectric elements.

AECL estimates that development of two prototypes would cost about $500K over a two year period from the end of 1977 to the end of 1979 or early 1980. One year of evaluation at Alert from the summer of 1980 to 1981, followed by production, would result in an installation date of the summer of 1982. The cost of the production units with a life of 5 years is estimated at $100K each. For a 5-year life, cost per year per site for ten years of operation for 10 sites would be $25K, $2.0M for generators and $0.5M for development. For a 10-year life this cost would be $15K per site per year. The individual units would weigh less than 3000 lb and occupy about 50 cu. ft.

The main advantages of this system are the lack of maintenance required and the ability of fulfilling the requirement of servicing and replenishment on a single yearly helicopter flight to all sites. Also, reliability should be high, because the generation of electricity would not depend on mechanically moving components.

WINDMILL-BATTERY SYSTEMS

The information in this section will be amplified in a subsequent report after a relevant task presently underway at DREO is completed (19). The estimates quoted in the following parts of this section are based upon the best available data at the time of writing this report. No significant changes in information are expected.

RELIABILITY

The effect of low temperature and icing on mechanical parts and linkages in an Arctic environment will have to be assessed. Eventually, as better DC generators become available they will also have to be assessed. To ascertain the size of the battery system needed, a detailed survey of windspeeds at the Arctic sites will have to be completed. For a preliminary estimate, a battery twice the size of the recommended standby power supply was chosen (see next section for details). This would provide 72 days of uninterrupted power even in the complete absence of windpower. Studies carried out in the Northwest Territories indicate that this size of battery would be sufficiently large so that the charging rates determined by wind profiles, in relation to the battery size, are sufficiently low that charge is accepted even at the low battery temperatures expected. This would have to be confirmed. Some mechanical servicing and replacement will be required, but the amount of maintenance is not known. It is expected that one yearly helicopter flight for all sites would be all that will be required for

servicing. Estimated life is somewhere between 5 and 10 years. A standby battery would not be necessary for this sytem.

SCHEDULING

The studies at DREO are expected to be completed at the end of 1978. Specifications and awarding of a contract for two prototype models could be accomplished by the end of 1979 with installation of the units in the Arctic in 1980 for evaluation. Because of the possible detrimental effects of the Arctic environment on the mechanical parts and linkages of the system, a 2-year evaluation is recommended. A contract for the required number of units could be awarded in 1982 with installation to take place in the summer of 1983.

COST, WEIGHTS AND SIZES

The wind turbine system would be similar to the one installed at DREO shown in Figure 6. The diameter of the wind turbine would be 15 feet and the turbine would be erected about 8 feet above the ground on a frame. The unit itself would have to be supported with guy wires. This would involve more site preparation than for the other systems. The cost of the two prototypes and two sets of lead/acid batteries for evaluation at Alert and the evaluation itself, would be about $40K. Estimated cost of the unit would be $5K including the charger for the batteries. The cost of the batteries would be $3.4K per site. Therefore, the initial capital costs per site would be $8.4K. For a 10-year life, the cost per year per site for 10 sites would be $1.24K, $40K development, $50K for windmills and $34K for batteries. For a 5-year life, the corresponding cost per site per year would be $1.74K. The weight of the system less batteries is expected to be 500 to 1000 lb. The shipping volume of the windmill if completely assembled would be over 3000 cu. ft. If disassembled the volume could be of the order of 150 to 200 cu. ft. The batteries would weigh 4800 lb and occupy 42 cu. ft.

STANDBY POWER SYSTEMS

For the standby power units which must go on automatically and give 30 days of operation, different considerations than those of the main power supply must be taken into account. The fuel cells, thermoelectric

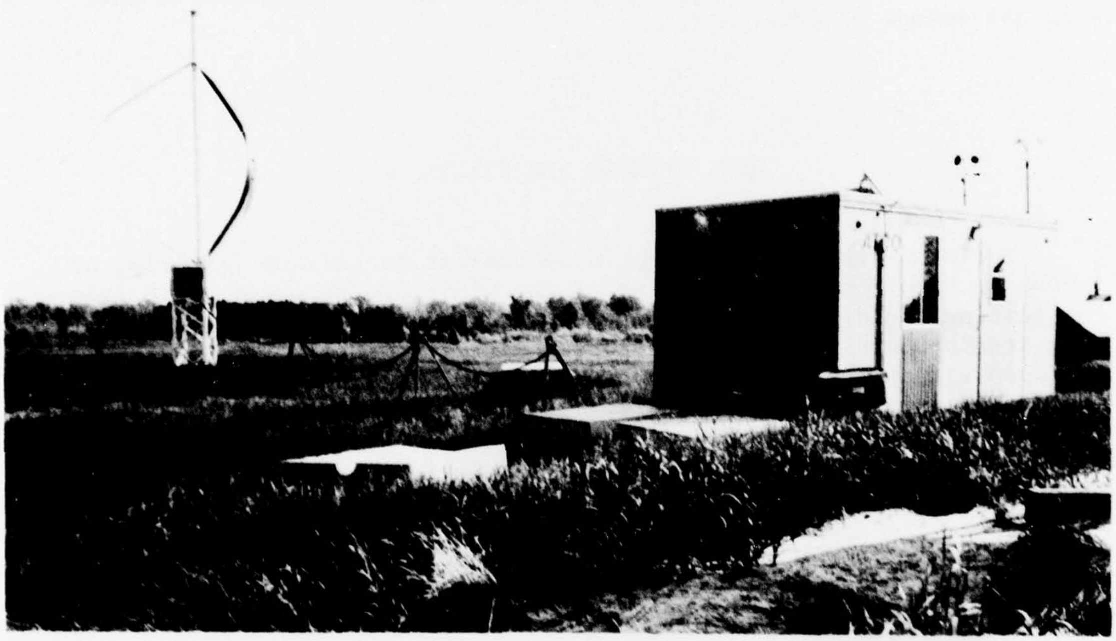


Fig. 6: Windmill-Battery System at DREO.

generators and windmill systems are not suitable as they would have to be kept "idling" and ready to provide full power at any time. For windmill systems, one could not always count on there being wind. The other systems would require a period of warmup to get the system up to operating conditions. Also it would not be desirable to have an identical system for the backup since the main system would then be duplicated in size and cost and there would also be the same reliability implications.

Primary batteries are not the best choice. It is probable that failure of the main power supply would occur during the extreme cold periods. Since the number of cells required depends upon the minimum temperature and the duration of operation at that temperature, it does not follow that for 30 days of operation one requires one-twelfth the number of cells. In calculating the number of cells required for the main power supply, use was made of the fact that the system would be at the low temperatures for less than half the time. For the standby mode the entire discharge could be at the low temperature. Since the number of cells needed for the Cipel batteries is determined by the current drain, to ensure operation at the required current at -55°C the same size of AD600 battery and two-thirds the number of AD608Z batteries for one year of operation would be required. One string of AD600 cells could not give the required current. The AD608Z battery could maintain the required current for the 30 days since the battery would only be about 15% discharged at that time. For the other primary cells the size of the battery would be determined by capacity delivered. A fewer number of cells would be required, but each cell would be discharged at a higher current drain and that would decrease the available capacity at low temperatures. At a current of about six times that used for calculation of the size of battery needed for one year's operation, the available capacity at -55°C would be about 50% of that at the lower rate. Therefore, a battery of one-sixth, not one-twelfth the size of the one-year battery would be required to give the 30 days operation at -55°C. This battery would still contain thousands of cells and intercell connections which could cause problems. Another disadvantage of the use of primary cells as standby power supplies is that once discharged, they would have to be replaced. The life of these cells would be about 5 years.

The only suitable cells to use as standby power are secondary cells. Unlike primary cells they could be recharged from the main power supply if discharged. In the event that the main power were to go off temporarily, say, because of extremely low temperatures, secondary batteries could easily supply the power. When the main power supply was back in service the standby power supply could be recharged. This system would require a charger capable of keeping the batteries on trickle charge. The charging current would be of the order of 0.1A and would not impose any severe demands on any of the main power supplies selected. The only system that might be affected is the zinc/air cell, but sufficient redundancy was allowed to compensate for this. At low temperatures, the self-discharge rate would be extremely low. A suitable charger that would allow the battery to be trickle charged at a low current, yet not discharge the main power supply or the standby battery if the main supply voltage fell between 10V and the voltage of the standby power supply, could be built for about $100 to $150 for the lead/acid system. The charger system for the nickel/cadmium system would be more complex and more costly.

Table III shows characteristics for secondary battery standby systems based on the batteries listed in Table II*. At a continuous maximum current drain of 2.2 amperes, for 30 days operation, 1584 Ah would be required. It is not possible to obtain exactly this capacity because of the sizes in which cells are available. The number of cells in parallel needed was determined by calculating the least number of cells required to give a minimum of 1600 Ah. The nickel/cadmium batteries would deliver 30 watts of power at a voltage of about 13V, sufficient to operate the regulator in the constant power mode. Only 6 lead/acid cells in series are recommended here as opposed to 7 for the main power supply. With the higher concentration of electrolyte needed, such a lead/acid standby battery would be operating at about 12.8V and deliver 26.5 watts. This is considered to be adequate for the standby mode.

Of the four systems listed in Table III and based on the cost and weight the Varta 480 Ah lead/acid cells or equivalent are recommended. The weight involved should make transportation in one helicopter flight possible. These cells have a life expectancy of 15 years, but this is for higher operating temperatures and lower electrolyte concentrations. It would be necessary to use an electrolyte with a specific gravity of 1.29**. According to the calculations of the type done earlier on secondary batteries, the electrolyte would not reach a specific gravity of 1.25 and a freezing point of -55°C until after the battery had been completely discharged. Studies to evaluate the behaviour and life expectancy of cells using the 1.29 sp. gr. electrolyte would cost about $25K.

CONCLUSIONS

The costs and availability of various candidate power supplies are summarized and compared in Table IV. The first two parameters are the dates when the particular systems will be available for installation and their estimated development costs. In the cases where development is required, the dates and costs are best estimates. The initial capital cost includes only the equipment itself. It does not include site preparation, transportation or the standby system except where noted. The yearly recurring items include such things as fuel or system replenishment. As mentioned earlier, transportation costs will depend greatly upon the mode of travel, and the urgency with which the articles are required at their destinations. For this reason, weights and volumes only are listed. In order to arrive at a cost over

* As in the earlier section on Secondary Batteries, the cell sizes and brands listed are not necessarily the recommended ones. They are merely typical of many brands.

** at 25°C/25°C.

TABLE III

30-Day Secondary Battery Standby Systems for Arctic Repeater System

System	# Cells (series x parallel)	Ah Capacity	Weight (lb)	Volume (cu. ft.)	Cost $**
Ni/Cd KAP 42 415 Ah*	40 (10 x 4)	1660	1680	15	8460
Ni/Cd L411 488 Ah*	40 (10 x 4)	1950	1680	15	10,020
Lead/Acid 480 Ah*	24 (6 x 4)	1920	2400	21	1670
Lead/Acid Planté 2200 Ah*	6 (6 x 1)	2200	4000	23	2850

* or equivalent

** 1976 prices

TABLE IV

Comparison of Various 30 Watt Power Supplies for Use in Arctic

A. BASIC POWER SUPPLY

Power Supply	Date Available for Installation	Estimated Development Testing and Evaluation Costs $(000)	Initial Capital Cost per Site ($)	Yearly Recurring Items	Transportation Required Wt and volume per site	10 year Cost per Site per Year for 10 Sites* ($)	Maintenance Required	Remarks
Cipel Zinc/Air AD6082 2000 Ah cells	1978	-	3960	Must replace batteries each year.	Each year must transport 3000 lb of batteries per site to Alert, 51 cu. ft. each. Weight from Alert to site 4200 lb.	3960	Must activate batteries at a battery shop at Alert.	Would require facilities for activating batteries. Only power supply that would be available in 1978 or 1979. Can be used as an interum power supply.
GE SPE Fuel Cell	1983	200	66,400	Fuel would have to be replaced each year. The fuel cells would have to be replaced each 3 to 5 years.	100 to 1570 lb of fuel and tanks each year, depending upon type of fuel used, (hydrogen as solid fuel or in high pressure or cryogenic tanks). Volume of fuel 10 to 48 cu. ft. Weight of fuel cell and drum 100-150 lb, volume 9 cu. ft.	9300	Must drain water from drum and replace fuel on a yearly basis.	Development work would be necessary on fuel cells and fuel. An air breathing system would be preferable. The system would require a 1 year evaluation at Ottawa and 1 year at Ellesmere Island. 2 fuel cells would be needed per site to provide backup. If tanks are used, 2 sets would be required per site, one for operation and one for refilling and transportation from producer to site.
TELAN 2 30 W Propane Thermoelectric Generator	1980-81	25	4000	Must replace fuel every year, generators every 5 years.	Yearly, 3570 lb of fuel and tanks, 190 cu. ft., weight and volume of generator 73 lb, 5.4 cu. ft.	1180	None other than replacement of fuel and checking burner yearly and possibly replacing generators every 5 years.	Schedule date and development costs depend on development of suitable heat exchanger and evaluations at Alert.

TABLE IV (Cont.)

Power Supply	Date Available for Installation	Estimated Development Testing and Evaluation Costs $(000)	Initial Capital Cost per Site ($)	Yearly Recurring Items	Transportation Required Wt and volume per site	10 Year Cost per Site per Year for 10 sites* ($)	Maintenance Required	Remarks
Radioisotopic Thermoelectric Generators	1982	500	100,000	Replace units every 5 years. To spread out costs could refuel 2 units each year.	Less than 3000 lb and 30 cu. ft. Initial installation only.	25,000 (15,000)	None.	Final figures will have to await outcome of feasibility study with AECL. 10 year life could be possible with re-design of the units. Cost per year per site for 10 sites is given in brackets for a 10 year life.
Windmill-Battery System	1981	40	8400**	Not known at this time, will have to await outcome of tests at DREO.	5300 to 5800** lb, 200 to 250 cu. ft. Initial installation only.	1,240 (1,740)	Normal mechanical servicing. Some replacement of parts may be required.	Studies not complete. Therefore cost, weights and maintenance required are only estimates. Also, life is an estimate, 10 years was assumed. If life is 5 years, get cost per year per site for 10 sites in brackets. Extensive site preparation and assembly will be needed.

* Includes development but not transportation costs.

** Includes secondary batteries, no further standby system required.

B. STANDBY POWER SYSTEMS

VARTA 480 Ah Lead/Acid Cells or equivalent	1978	25	1670	None.	Initially 2400 lb at 21 cu. ft. Thereafter a small quantity of water for topping up electrolyte.	167	Electrolyte level would have to be checked and additions made, if required, once a year.	The life, using specific gravity of 1.29 at 25°C, would have to be checked. Possibly these batteries could last up to 15 years then the cost per year per site could be as low as $100. Costs do not include a trickle charger for batteries, estimate $100.

10 years, the cost per site per year for 10 sites was calculated. This amount includes development costs, but excludes transportation, site preparation and the standby system costs. Maintenance requirements and general considerations complete the table.

Although listed last in the table, the standby power system will be discussed first as it is common to all the other systems. The best all around system is the Varta 480 Ah lead/acid or equivalent system. The weight, and cost per site, both for the initial installation and amortized over a 10-year period, are moderate. These cells are readily available and would not require significant maintenance over a 10-year period. It is not expected that the use of a higher concentration of electrolyte would have any significant effect on the life of the batteries at the temperatures of operation in the north.

From the dates that the systems will be ready for installation, it can be seen that only one system could be used in 1979. This is the Cipel zinc/air system. It could be considered as an interim system, because on the basis of weight and cost, it is by no means the best system. Also, the sites could not be serviced on a single yearly helicopter flight to all sites. One or more flights to each site would be required. If each parallel string in the battery were fitted with a diode and there was sufficient space available at the sites for two sets of batteries, it would be advantageous to remove the supposedly spent batteries after two years rather than after one. The used battery would still have some capacity when the time came to replace it. If the used and the replacement batteries were connected in parallel, the used one could continue to give electricity until it was exhausted to a voltage below the cutoff of the diode. It is conceivable that this could result in a saving of one battery in ten.

The remaining systems, since they will not be available by 1979, can be divided into two categories depending upon whether development, initial capital and amortized costs are low or high. The low cost category includes the windmill-battery system and fueled thermoelectric generators. The high cost category require extensive costly development and include fuel cells and radioisotopic thermoelectric generators. The high cost systems would not be available as soon as the low cost systems.

Of the low cost systems, the windmill-battery system is chosen to be the most attractive since it does not involve the transportation of fuel. However, its reliability has not been completely checked and extremely low environmental temperatures could have an adverse effect on it. Even if its life was only two years the cost per site per year would be \$3.24K (\$40K for development, \$34K for the batteries and \$250K for the windmills). However, a weight of 500 to 1000 lb per site would have to be transported only every other year. This in itself would result in considerable savings.

We can consider the initial capital cost and weight of tanks and fuel for the fueled thermoelectric generators to be comparable to the weight and cost of Cipel cells. If the extra volume occupied by the propane tanks does not present too great an increased transportation cost over the battery system, the cost of replenishment of fuel is very much less than the replacement of the Cipel batteries. The 10-year amortized cost is only one-quarter that of the batteries and of that only one-quarter is for fuel, the rest is

for initial capital cost and development.

Fuel cells, with the exception of SPE fuel cells, and radioisotopic thermoelectric generators are high cost systems because of significantly higher development and initial capital costs. Since a large portion of the amortized costs is involved with the development of the units and initial purchases, significant savings could be realized if the advances made by the manufacturers were followed to see if units can be purchased, so to speak off-the-shelf, at a later date and at prices lower than those quoted in Table IV. This approach could be especially beneficial for the development of the radioisotopic thermoelectric generator and the high pressure or cryogenic tanks for fuel cells. However it is unlikely that the systems would be available on the dates quoted in Table IV.

SPE fuel cell with high pressure or cryogenic hydrogen tanks and based on the amortized figures in Table IV, would be less expensive than the zinc/air batteries, if the cost of transportation to Alert alone is greater than $2.60 per lb. The corresponding breakeven figure for the hydride system would be about $1.70 per lb. Fuel cells, therefore, should not be ruled out because of high initial and transportation costs. Their low weight especially when it is estimated that the costliest portion of the transportation bill will be from Alert to the site may make them the preferable system. Also, it is estimated that the cost for the fuel cell itself, if purchased off-the-shelf would be about $2K per year per site. They would be lighter and less costly than the Cipel batteries and fueled thermoelectric generators, but more expensive than the windmill-battery system. The only area in which they could be better than the windmill system would be on a reliability basis.

The lowest price one could expect to pay for the radioisotopic thermoelectric generator would be about $75K each. If these had a life of 10 years, the cost per year per site would be $7.5K. At this price, the system would have to be compared closely to the fuel cell systems costing $2K to $3K per site because fuel would not be required every year. It would also have to be compared closely to the low cost systems because of its reliability and lack of requirement for maintenance or for transportation of fuel. A radioisotopic thermoelectric generator with Strontium 90 and a life of 25 years would be the least expensive of all the systems.

The initial installation weights, including the standby battery where applicable, do not vary greatly. The Cipel battery, windmill and radioisotopic thermoelectric generator system are all in the 5000 to 5800 pound range and would involve similar initial transportation costs. The fueled thermoelectric generator would be about 500 pounds more than the above mentioned systems. Using the extreme figures of $0.20 and $2.50 per pound for transportation would result in an increased cost of $100 to $1.25K per site. These figures still make the cost of using the fueled thermoelectric generator comparable to the initial capital cost of the best system, the windmill-battery. The SPE fuel cell, depending upon the fuel used, would have a lower unit weight than the windmill or batteries by about 1000 to 2400 pounds. The corresponding saving in transportation costs would be $200 to $6.0K and therefore deserves further consideration. As can be seen from Table IV, the initial costs of the fuel cells would still be significantly higher than the other systems with the exception of the radioisotopic thermoelectric generator.

All of the systems except the batteries would require site preparation. Possibly the system requiring the most would be the windmill, which would need a base pad or anchors for the windmill tower plus three anchors for the guy wires. The other systems would also need anchors or guy wires, but not to the extent of the windmill-battery system. However, the added cost is not believed to be significant because the majority of cost will be in transporting the crew and materials. The extra time required to prepare the site for the windmill would form a small part of the total cost.

RECOMMENDATIONS

1. A more detailed survey of temperature and wind speeds for the proposed sites should be carried out to determine if there is sufficient wind and whether -55°C is a realistic minimum temperature.

2. Cipel zinc/air batteries equipped with diode protection should be used as an interim power supply until a lighter and/or less expensive system can be developed. It is further recommended that the batteries be removed after two years and not one year in service. Since some capacity will still be available after one year of use, the old and new batteries can then be used in parallel until the old one is completely exhausted.

3. Lead/acid batteries equivalent to the Varta 480 Ah cells should be used as the standby power system. The electrolyte specific gravity would have to be increased to 1.29 at 25°C. Studies should be undertaken to determine if a higher acid concentration will have an adverse effect on these batteries.

4. Work should continue on the windmill-battery system as a possible low cost power supply to determine its reliability in an arctic environment.

5. Work should continue on the evaluation in an arctic environment of the catalytic thermoelectric generator, to determine its reliability and efficiency and to develop a suitable heat exchanger for the propane fuel at low temperatures. This system should be considered as the alternative or back-up to the windmill system as a low cost power supply.

6. The feasibility of using fuel cells with various types of hydrogen fuels should be investigated further. Fuel cells should be considered in spite of their high initial costs because of the low weight of both the system and the fuel required for replenishment.

7. Specific work on radioisotopic thermoelectric generators beyond the present feasibility study with AECL cannot be recommended at this time. The cost per unit has to be reduced or the efficiency increased, and the present

reliability of fuel supply has to be increased. New developments should be followed because of the long life and maintenance-free aspects of the system. It could be a strong contender in spite of its high initial cost, especially if the cost of transporting fuel from Alert or Eureka to the site is excessive.

8. Any system chosen to replace the interim Cipel batteries should be evaluated at an actual site. The power supply it is intended to replace and standby battery should be used for back-up.

9. A more detailed study of transportation costs should be carried out, with emphasis on transportation from Alert or Eureka to the sites. This could be done best by operations people who are more familiar with the actual costs and with the varied and most efficient methods of transportation.

ACKNOWLEDGEMENTS

The author wishes to thank Dr. R.M. Hayashi of DREO for his critical review of this report and for helping in obtaining and coordinating some of the data, especially on radioisotopic thermoelectric generators. The author also wishes to thank the following members of the DREO staff for their comments and help in providing data: Messrs. W.A. Armstrong and W.J. Moroz on primary batteries; Dr. E. Valeriote on secondary batteries; Dr. C.L. Gardner and Mr. E.E. Criddle on fuel cells; Dr. J.R. Coleman, Mr. R. McMahon and Mr. H.R. Braun on fueled thermoelectric generators; and Capt. D. Bristow on windmill-battery systems and radioisotopic thermoelectric generators.

REFERENCES

1. PDP G1413. Alert-Ottawa Medium Data Rate Communication System, file 3656-5-1413, 19 August 1976, (draft).

2. CD 3655016, Unattended Radio Relay Station. Honeywell Incorporated, March 3, 1976.

3. Minutes of Progress meeting on Arctic Repeater Station, Communications Security Establishment (CSE), Oct. 4 and 5, 1976.

4. DND Task DCEM 30, "Research and Development Support on Power Supplies for Arctic Radio Repeater Systems", DREO PCN 25A29.

5. Data from SAFT Corporation, France. Supplied by Cipel & Le Carbone with other data on performance of zinc/air cells.

6. Climate Normals. Vol. 1 Temperatures. Department of Transport, Meteoroligical Branch, Toronto, 1968.

7. Private communication, CSE File No. R/56/77, 28 February 1977.

8. Honeywell Corporation. Private communication, October 5, 1976.

9. G.W. Vinal, Storage Batteries, Third Edition, John Wiley and Sons Inc. (1955).

10. Fuel Cells - A Survey, B.J. Crane, Technology Utilization Series NASA-SP-5115, Washington, 1973.

11. ALSTHOM-EXXON, Massey France, private communication.

12. Private communication, W.G. Tasthek, MERADCOM/C.L. Gardner, DREO, 17 January 1977.

13. J.G. Finegold, "Liquid Hydrogen as an Automotive Fuel", p. 224, Application of Cryogenic Technology, Vol. 6, Scholium International Inc. (1974).

14. DREO unpublished results by R.L. Haines.

15. Department of Indian and Northern Affairs. Letter C.W. Bresee/C.L. Gardner, file T3566-1 (A-4), November 22, 1974.

16. T.J. Palmer, Cipel and Le Carbone, Valleyfield, Quebec. Private communication, October 7, 1976.

17. Contract Demand 3206419, Study of Radioisotopic Thermoelectric Generator, AECL Canada, March 1977.

'8. Private communication, Mr. Ron Creamer, Hanscom Airforce Base, Mass., Sept. 29, 1976.

19. DND Task DCEM 29 "Low Power Wind Turbine-Battery System for Arctic", DREO PCN 25A25.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATING ACTIVITY Defence Research Establishment Ottawa National Defence Headquarters Ottawa, Ontario, Canada K1A 0Z4	2a. DOCUMENT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. DOCUMENT TITLE

POWER SUPPLIES FOR ARCTIC RADIO REPEATER SYSTEMS (U)

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

REPORT

5. AUTHOR(S) (Last name, first name, middle initial)

NAGY, Gerard D.

6. DOCUMENT DATE AUGUST 1978	7a. TOTAL NO. OF PAGES 42	7b. NO. OF REFS 19

8a. PROJECT OR GRANT NO. 54-03-07	9a. ORIGINATOR'S DOCUMENT NUMBER(S) DREO REPORT NO. 787
8b. CONTRACT NO.	9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

10. DISTRIBUTION STATEMENT

UNLIMITED DISTRIBUTION

11. SUPPLEMENTARY NOTES	12. SPONSORING ACTIVITY DCEM

13. ABSTRACT

This feasibility study assesses various long-lived self-contained 30 watt power supplies for an Arctic Radio Repeater system. The study involves a review of the state-of-the-art, availability and cost of five candidate systems; batteries, fuel cells, radioisotope thermoelectric generators, fueled thermoelectric generators and windmill-battery systems. Also included in the study are standby reserve units which could be any of the above five candidates. Reliability and service and maintenance requirements are considered, as the requirements call for reliable one year unattended operation and servicing by light helicopter on a single annual flight for all sites.

Only zinc/air batteries with lead acid batteries for the standby system are available now. Their cost is moderate, but the zinc/air cells are heavy and must be replaced each year. The other systems could be available in the 1980's but they would require various amounts of development work and evaluation in an arctic environment. Recommendations and priorities for development of the systems that could replace the zinc/air cells at a later date are given.

UNCLASSIFIED

DSIS
72-508

UNCLASSIFIED
Security Classification

KEY WORDS
ARCTIC OPERATIONS LOW TEMPERATURE OPERATION POWER SUPPLIES PRIMARY BATTERIES RADIO REPEATER SYSTEMS RADIOISOTOPIC THERMOELECTRIC GENERATORS THERMOELECTRIC GENERATORS SECONDARY BATTERIES WINDMILL POWER SUPPLIES

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the organization issuing the document.

2a. DOCUMENT SECURITY CLASSIFICATION: Enter the overall security classification of the document including special warning terms whenever applicable.

2b. GROUP: Enter security reclassification group number. The three groups are defined in Appendix 'M' of the DRB Security Regulations.

3. DOCUMENT TITLE: Enter the complete document title in all capital letters. Titles in all cases should be unclassified. If a sufficiently descriptive title cannot be selected without classification, show title classification with the usual one-capital-letter abbreviation in parentheses immediately following the title.

4. DESCRIPTIVE NOTES: Enter the category of document, e.g. technical report, technical note or technical letter. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the document. Enter last name, first name, middle initial. If military, show rank. The name of the principal author is an absolute minimum requirement.

6. DOCUMENT DATE: Enter the date (month, year) of Establishment approval for publication of the document.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the document.

8a. PROJECT OR GRANT NUMBER: If appropriate, enter the applicable research and development project or grant number under which the document was written.

8b. CONTRACT NUMBER: If appropriate, enter the applicable number under which the document was written.

9a. ORIGINATOR'S DOCUMENT NUMBER(S): Enter the official document number by which the document will be identified and controlled by the originating activity. This number must be unique to this document.

9b. OTHER DOCUMENT NUMBER(S): If the document has been assigned any other document numbers (either by the originator or by the sponsor), also enter this number(s).

10. DISTRIBUTION STATEMENT: Enter any limitations on further dissemination of the document, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this document from their defence documentation center."

(2) "Announcement and dissemination of this document is not authorized without prior approval from originating activity."

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document, even though it may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall end with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (TS), (S), (C), (R), or (U).

The length of the abstract should be limited to 20 single-spaced standard typewritten lines; 7½ inches long.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a document and could be helpful in cataloging the document. Key words should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context.